Ankle kinematics during walking in patients with ankle arthrodesis

Kinematyka stawu skokowego w trakcie chodu u pacjentów po operacyjnym usztywnieniu stawu

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Key words
locomotion, ankle arthrodesis, three–dimensional gait analysis

Abstract
Background: Osteoarthritis, which causes pain, deformities and instability of the rearfoot, is the most common indication for ankle arthrodesis. The aim of this study was to present the influence of the ankle arthrodesis on the performance of this joint in the three planes during walking at natural velocity.
Materials and methods: Fourteen patients, age from 34 to 66 years (mean: 54 years), with ankle arthrodesis participated in the testing procedures. Angular changes of the ankle in the three planes of movement during particular gait phases and spatiotemporal gait parameters were evaluated by a three–dimensional motion analysis system, Vicon®. The study was performed at the Biokinetics Laboratory of the Academy of Physical Education in Kraków. The results of locomotion analysis were compared to a control group, consisting of thirty healthy persons aged 40–65 years.
Results: In the saggital plane feet joints worked symmetrically during all gait phases, but there were angular changes of plantar and dorsal flexion, which were different from biomechanical norm. In frontal plane, feet were in abduction during almost all gait phases. In the transversal plane, feet were in internal rotation. Significant differences in spatiotemporal gait factors were observed between the two groups.
Conclusions: Ankle arthrodesis leads to significant changes in motion pattern of the ankle joints.

Słowa kluczowe
lokomocja, artrodeza stawu skokowego, trójwymiarowa analiza ruchu

Streszczenie
Wstęp: Celem badań jest przedstawienie wpływu zabiegu artrodezy stawu skokowego na trójpłaszczyznową pracę stawu w trakcie chodu z naturalną prędkością.
Materiał i metoda: Badania zostały przeprowadzone u 14 chorych wieku od 34 do 66 roku życia (średnia wieku 54 lata), u których przeprowadzony został zabieg artrodezy prawego stawu skokowego. Oceniane były zmiany kątowe stawów skokowych w trzech płaszczyznach ruchu w poszczególnych fazach chodu oraz parametry czasowo-przestrzenne chodu. Wyniki badań lokomocji zostały przedstawione na tle grupy porównawczej 30 zdrowych osób w przedziale wieku 40–60 lat.
Wyniki: U badanych osób odnotowano zmianę schematu pracy w trzech płaszczyznach ruchu w porównaniu z wykresami grupy kontrolnej.
Wnioski: W wyniku operacyjnego usztywnienia stawu skokowego dochodzi do istotnych zmian wzorca ruchowego stawów stopy.

Introduction

Pronounced degenerative changes with concomitant incomplete, painful, connective tissue-mediated stiffening of the joint constitute an indication for surgical arthrodesis of the upper ankle joint[1].

As a result of the surgery, physiological range of dorsal and plantar flexion is lost and this function is taken over by Chopart joint, with the range of motion increased sufficiently to correct for arthrodesis-induced dysfunction that becomes insignificant or unnoticeable[1,2,3].

According to DiNapoli and Ruch[4] disturbances causing pain, deformation or instability of the posterior part of the foot constitute indication for arthrodesis.

Scholarly literature describing locomotion in persons after ankle arthrodesis[5,6,7] indicate significant loss of function of the arthrodesis-subjected joint in three planes of motion.

It seems, therefore, justified, to conduct studies aiming at description

Authors' contribution: A – project of the study, work; B – collection of the data, information; C – statistical analysis; D – data interpretation; E – preparation of the manuscript; F – literature query; G – obtaining funds

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of movement pattern of the ankle joint during walking at natural velocity using results of a three-dimensional motion analysis.

The aim of this study was to use a three-dimensional movement analysis to assess kinematic parameters of gait in patients after ankle arthrodesis.

Values of angular changes in the ankle joints and spatiotemporal gait parameters: cadence, step length, walking speed, stride length, double support time, step time and stride time were evaluated.

Material and method

Locomotion analysis was conducted in 14 patients (10 women, 4 men) aged from 34 to 66 years (mean age: 54 years), who had undergone right ankle arthrodesis. The procedure had been performed approximately 5 years before initiation of this study. Ankle joints of the patients were fixed at plantar flexion (mean: 6º). Arthrodesis was performed in the patients due to secondary degenerative changes. In the evaluated group, no other health problems were observed that would affect gait stereotype. Group characteristics are presented in the Tables 1 and 2.

Control group included 30 healthy persons aged from 40 to 60 years (the so-called biomechanical norm).

Assessment of locomotion was conducted in the Laboratory of Biokinetics, Chair of Anthropomotorics at the Academy of Physical Education in Krakow, Poland.

To determine motion trajectory, a system for three-dimensional motion analysis, Vicon, was used that is based on passive markers stuck at axes of joint movements and at selected anthropometric sites of the body. The markers are stuck directly on the skin of the examined person at characteristic points: on the thorax, pelvis, extremities and the head, according to a scheme corresponding to the biomechanical model „Golem". This enables spatial reconstruction of body segments.

Table 1

Characteristics of the evaluated group		
parameter	$\bar{x}$ ± sd	min – max
age [years]	54.7±10.5	34-66
weight [kg]	85.3±13.5	62-100
height [cm]	166.6±7.9	160-180

Table 2

Range of motion in the ankle joints		
	$\bar{x}$ ± sd	min – max
dorsal flexion of the ankle joint (healthy)	15±7.1	0-20
plantar flexion of the ankle joint (healthy)	36.4±13.5	10-50
pronation (healthy)	17.9±6.4	10-25
pronation (after surgery)	8.3±5.2	2-18
supination (healthy)	23.6±9.9	10-35
supination (after surgery)	9.3±6.1	5-20

The obtained information is presented in a form of plots using the „Polygon" software. The software creates a multimedia report containing the following information:

a) graphic representation in a form of plots of particular articulations in three planes, changes in angular velocity and acceleration in particular joints and changes in the length of selected muscles,
b) descriptive data that provide information about changes in spatiotemporal parameters: speed, cadence and step length, duration of particular gait phases,
c) animation of the skeleton with selected muscles, moving in a three-dimensional space.

In the presented work, graphic reports of angular changes and descriptive data were used.

In the analysis of locomotion, the Rancho Los Amigos Medical Center classification of gait phases[8] was used that assumes that single gait cycle constitutes 100%. The system distinguishes the following gait phases:

1. *initial contact* – placement of the heel onto the ground – 0%
2. *loading response* – loading of the extremity – 0-10%
3. *midstance* – middle part of the single stance phase – 10-30%
4. *terminal stance* – terminal part of the stance phase – 30-50%
5. *preswing* – take off – 50-60%
6. *initial swing* – take off of the toe – posterior swing – 60-70%,
7. *midswing* – transfer of the limb – 70-85%
8. *terminal swing* – anterior swing – 85-100%.

Results

Analysis of angular changes

On Figures 1, 2, and 3, mean values of angular changes in the ankle joints for 14 evaluated persons were presented in three planes of motion. Grey band on each plot represents variability of results in healthy population (mean±2SDs) – the so-called biomechanical normative data.

The ankle joints function symmetrically during the whole gait cycle. During the loading response phase, the excessive plantar flexion was evident that was (a maximum) 8º in the non-operated joint and 7º in the operated joint. During stance, angular changes fall within the biomechanical norm; however, there is a lack of plantar flexion, characteristic for the swing phase. During preswing, maximum dorsal flexion in the ankle joints is approximately 20º. Beginning with the terminal swing phase, the joints undergo excessive plantar flexion that exceeded normal range and was 7º. (Figure 1).

Pronounced changes in the position of the ankle joints are evident in frontal plane. Work of the joints is symmetrical, yet, it significantly exceeds the normal biomechanical range. The ankle joints are positioned in abduction during almost the whole gait cycle.

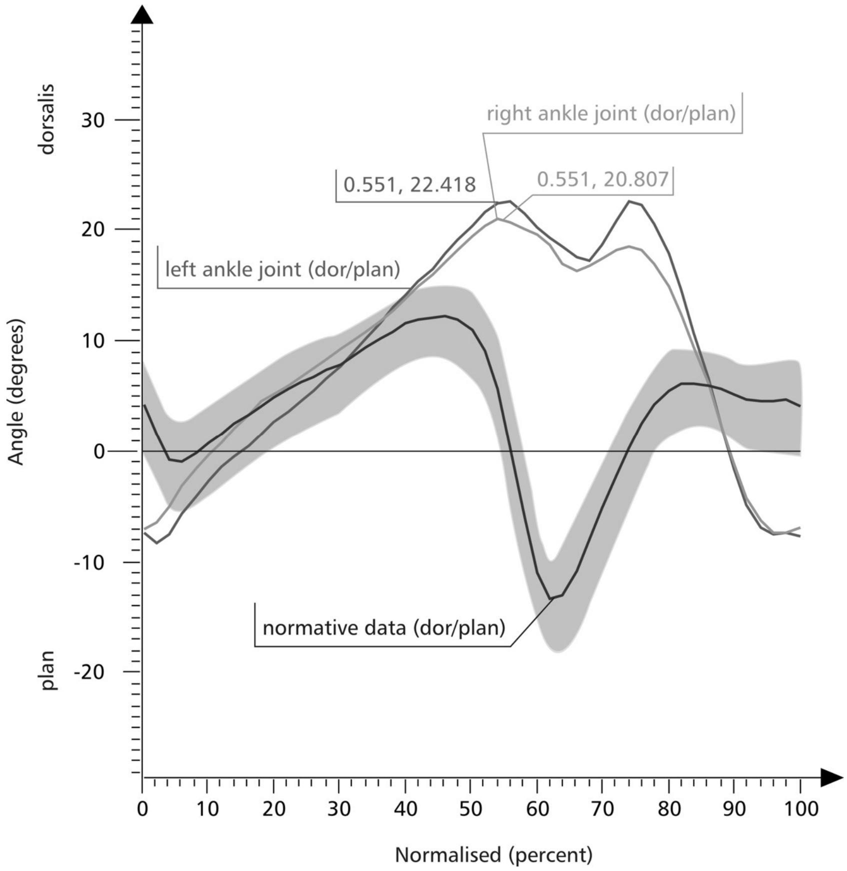

Figure 1
Angular changes in the ankle joints in saggital plane

Angle (degrees) – angular values in the evaluated joints (expressed in degrees); **Normalised (percent)** – normalised duration of the complete gait cycle (expressed as percent valules); **normal** – angular changes observed during normal gait, represented by the comparison group (mean and 2 SD); **Dors.** – dorsal flexion, **Plan.** – plantar flexion,

During initial contact, the stiffened joint is at slight adduction – approximately 2º, subsequently, marked abduction occurs – maximum value of this motion is approximately 11º during preswing. By the end of the terminal swing phase, the joints returns again to excessive adduction.

Initial adduction of the non-operated ankle joint is slightly greater - 3º; in contrast, abduction, occurring during the middle part of the cycle, is reduced. Greatest abduction of the joint occurs during preswing and is approximately 9º (Figure 2).

During the whole gait cycle, angular changes in transverse plane were characterised by a shift of range of motion of both feet towards external rotation as compared to the biomechanical normative data. However, excessive rotation is more pronounced in the operated limb – maximum difference between the values of angular changes for both feet was 10º during the stance phase (Figure 3).

Analysis of spatiotemporal gait parameters

To determine the range of dysfunction of the muscle-skeletal system, characteristic for post-ankle arthrodesis patients, all persons were measured spatiotemporal gait parameters during the assessment. The results are presented in the Table 3 and they represent mean values of spatiotemporal parameters for the left and right lower extremity and analogical parameters obtained for healthy persons from the control group.

The evaluated persons performed 98 (±13) steps per minute on average. Double support time was 0.37 s (±0.12) for the operated limb and 0.38 s (±0.13) for the non-operated limb, while single support time was 0.43 s (±0.05) for the operated limb and 0.44 s (±0.04) for the non-operated limb respectively. Mean step length of the operated limb was 0.53 m (±0.05) and was 0.51 (±0.09) for the non-operated limb; step time was 0.62 s (±0.1) for the operated extremity and 0.63 s (±0.08) for the non-operated extremity; further, stride length was 1.04 m (±0.14) and 1.05 m (±0.13) and stride time was 1.24 s (±0.17) and 1.03 s (±0.04) respectively. The studied persons' mean walking speed was 0.86 m/s (±0.05).

Discussion

Ankle arthrodesis is a recognised method of therapy of degenerative changes of the ankle joint in cases, where preventive treatment is ineffective[6,7].

The principal aim of surgery is to eliminate joint deformities resulting from degenerative changes, reduction of pain and improvement of joint stability[9]. However, the procedure induces significant limitation of patient's locomotion.

The three-dimensional motion analysis conducted in 14 persons demonstrated pronounced variability among the results. Despite the fact that the ankle joints operate symmetrically, motion pattern is significantly reversed.

In sagittal plane, during the swing phase, excessive dorsal flexion is present, while in frontal plane, , the feet are positioned in abduction – the maximum angular value (11º for the operated and 10º for the non-operated limb) occurred during the preswing phase. This abduction may result from compensatory movements in the lower ankle joint and the Chopart joint. Increased external rotation of the joints is also observed during the whole gait cycle.

As a result of stiffening, the feet are positioned in dorsal flexion and excessive supination and external rotation during stance, whereas during the swing phase, only does motion pattern in sagittal plane change. There is no physiological plantar flexion – the ankle joint is maintained in dorsal flexion. The flexion results from compensatory movement in the Chopart joint.

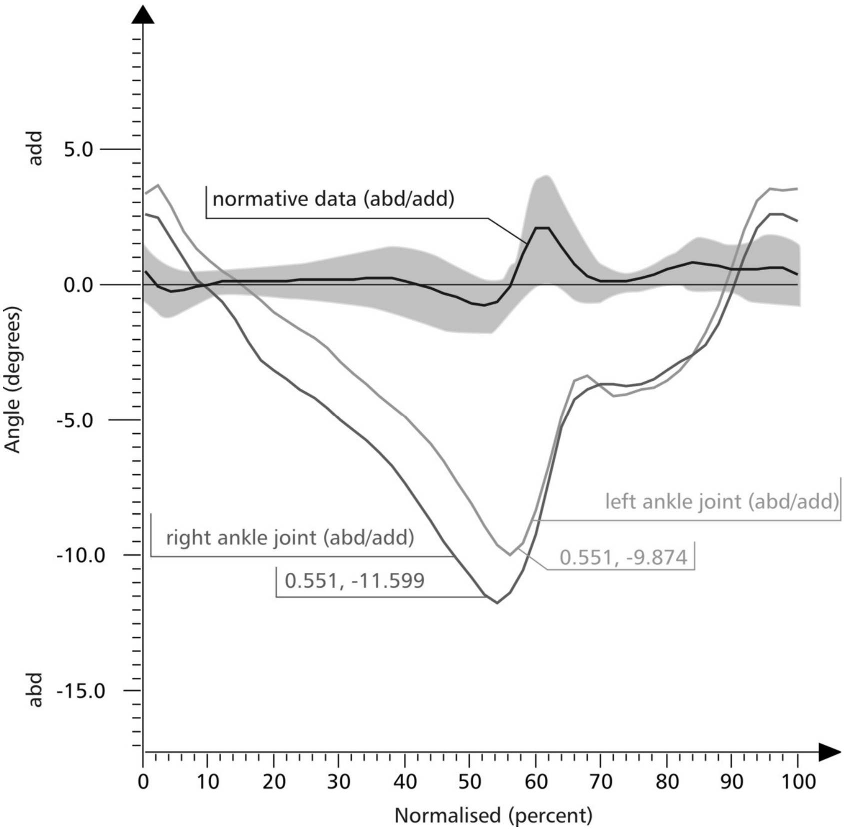

Figure 2
Angular changes in the ankle joints in frontal plane
Abd – abduction, **Add** – adduction

Thomas et al.[7] concludes that the range of motion is reduced in three planes during walking as a result of arthrodesis, however, range and direction of those changes is not reported. Wen-Lan et al.[9], who also used a three-dimensional motion analysis in his study, reports that in sagittal plane, the ankle joints are positioned in dorsal flexion during the whole gait cycle. However, in frontal plane, during stance, the feet are maintained in a neutral position, while during the swing phase – in pronation. motion pattern in transverse plane is also somewhat different – movement of the feet ranges from a neutral position during stance to increased external rotation during swing.

Based on the conducted analysis of spatiotemporal parameters of gait, it can be noted that the single support phase was shorter, while the double support phase was longer as compared to the biomechanical norm; step and stride lengths were also reduced, whereas step and stride times were prolonged. Such picture of gait cycle may indicate presence of a formed compensatory mechanism.

The evaluated persons performed an average of 98 steps per minute and walked at a velocity of 0.86 m/s.

Analysis of time parameters, conducted by Wen-Lan et al.[9], comprised only cadence and was 106 steps per minute, whereas data obtained by Beyaert et al.[6] indicate mean cadence of 110 steps per minute with walking speed of 1.09 m/s. Different results were also obtained by Thomas et al.[7], who observed a cadence of 106 steps per minute with walking speed of 1.06 m/s; additionally, stride length is also reported that was 1.19 m. Those differences may result from individual selection of walking speed by the patients. If a higher or lower velocity had been forced in the evaluated group, this would have likely induced a change in particular spatiotemporal gait parameters.

Based on the conducted three-dimensional motion analysis, a change in gait pattern can evidently be recognised in post-arthrodesis patients as well as degree and range of these dysfunctions can be determined. Therefore, monitoring of treatment of post-surgery patients is one of the possibilities of application of this study method. The obtained results can be used to assess and verify the effectiveness of applied therapeutic methods.

Table 3

Values of the spatiotemporal parameters of gait

Parameters	P $\bar{x} \pm$ sd	L $\bar{x} \pm$ sd	Normal – value
Cadence [st/min]	98.3(±13)	98.1 (±12.9)	113
DS [s]	0.37(±0.12)	0.38(±0.13)	0.19
SS [s]	0.43(±0.05)	0.44(±0.04)	0.47
SL [m]	0.53(±0.05)	0.51(±0.09)	0.69
ST [s]	0.62(±0.1)	0.63(±0.08)	0.54
StL [m]	1.04(±0.14)	1.05(±0.13)	1.38
StT [s]	1.24(±0.17)	1.24(±0.17)	0.95
WS [m/s]	0.86(±0.21)	0.87(±0.21)	1.30

$\bar{x} \pm$ sd – arithmetic mean ± standard deviation; **P –** right ankle joint; **L** – left ankle joint; **Normal** – values represented by the comparison group; **Cadence** – number of steps per minute; **DS** (double support) – duration of double support; **SS** (single support) – duration of single support; **SL** (step length) – length of the step; **ST** (step time) – duration of the step; **StL** (stride lenght) – length of the stride / gait cycle; **StT** (stride time) – duration of the stride / gait cycle; **WS** (walking speed) – gait velocity

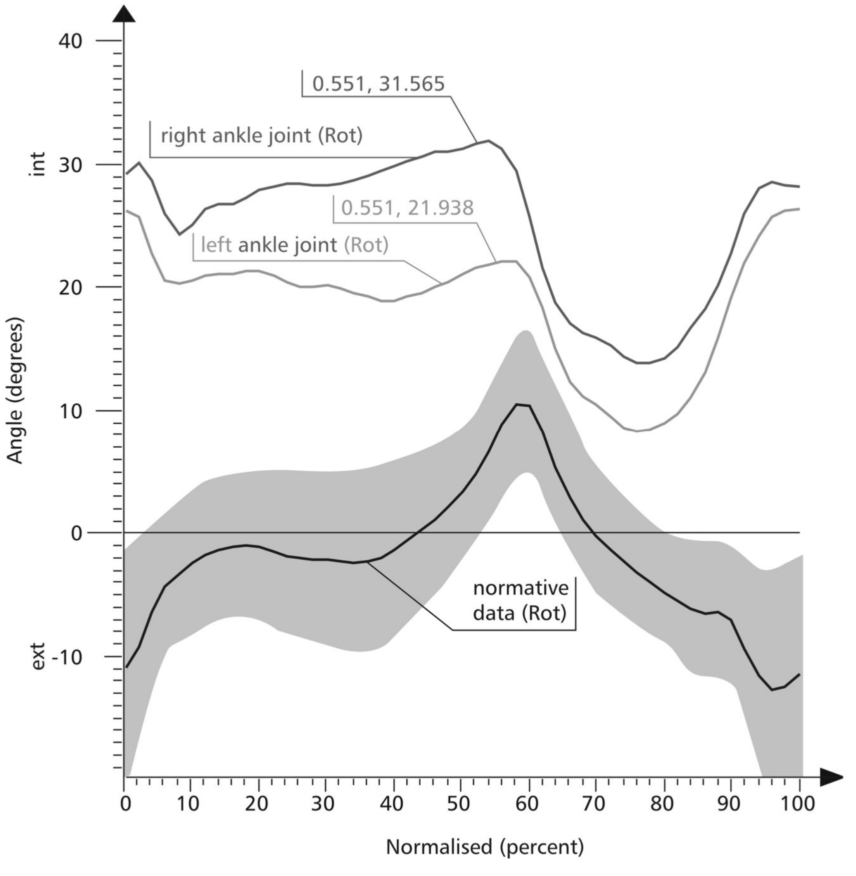

Figure 3
Angular changes in the ankle joints in the transverse plane
Ext. – external rotation, **Int.** – internal rotation, **Rot** - rotation

Conclusions

1. As a result of surgical ankle arthrodesis, motion pattern of the ankle joints is reversed.
2. The joints are positioned at excessive external rotation and supination and movement in sagittal plane is overtaken by Chopart joint.
3. The conducted analysis of spatio-temporal parameters indicates formation of compensatory mechanisms during patients' walking.

References

1. Tylman D., Dziak A., Ramotowski W., Lisicki K., Chomicz J.: Uszkodzenia goleni. W: Traumatologia narządu ruchu. Tom II. Pod red.: Tylman D., Dziak A., PZWL, wyd.II, Warszawa 1996
2. Kubacki J.: Zarys ortopedii I traumatologii. Wydawnictwo AWF Katowice, wyd.II, Katowice 1999
3. Dziak A.: Podstawowo zabiegi lecznicze w ortopedii. W: Podstawy ortopedii. Pod red.: Żuk T., Dziak A., Gusta A., PZWL, wyd.IV, Warszawa 1983
4. DiNapoli D., Ruch J.: Triple arthrodesis and subtalar joint fusion. Comprehensive Textbook of Foot Surgery, vol.2, Williams and Wilkins, Baltimore 1992
5. Lauge – Pedersen H.; Percutaneous arthrodesis. Acta Orthopaedica Scandinavica supplementum, 2003; 74, 307
6. Beyaert C., Sirveaux F., Paysant J., Mole D., Andre J-M. The effect of tibio-talar arthrodesis on foot kinematics and ground reaction force progression during walking. Gait Posture, 2004; 20: 84–91
7. Thomas R., Daniels T., Parker K. Gait analysis and functional outcomes following ankle arthrodesis for isolated ankle arthritis. Gait Posture, 2006; 88-A (3): 526–535
8. Perry J. *Gait analysis*. Thorofare, SLACK 1992
9. Wen-Lan W., Fong-Chin S., Yuh-Min Ch., Pen-Ju H., You-Li H., Cheng-Kuo Ch. Gait analysis after ankle arthrodesis. Gait Posture, 2000; 11: 54–61

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